International Journal of Engineering and Science Invention (IJESI)
ISSN (Online): 2319-6734, ISSN (Print): 2319-6726
www.ijesi.org ||Volume 11 Issue 10 October 2022 || PP 63-68

Green Chemical Technologies for Sustainable Developments in Industry

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Abstract
The 21st century will pose new and alarming challenges to chemi- cal engineering— a change in the raw material base, increasing en- vironmental considerations and the necessity to apply new meth- odological approaches. This century will however, creep into more industries like the electronic industry,pharmaceutical industry, bio- technology and other industrial sectors, namely agriculture and food production.
The challenges facing the sustainability of technological advance- ment of chemical industry today are re-inventing the use of materi- als. To address these challenge, green chemical technologies is es- sential to many of the environmental and resource use problems at the heart of sustainable development. These technologies are, there- fore, viable, cost-effective, environmentally advanced and most ap- propriate to the climatic, economical, geographical, ecological and social conditions of the country. This purpose can only be achieved by developing new environmental friendly, safe and nontoxic mate- rials and their based innovative technologies. Therefore, CPI must support sustainable development by investing in green technologies and ensure increased adherence to safety, health and environmental standards.
Keywords: *Green technologies, sustainable development, environ- mental, CPI, renewable resource*

I. INTRODUCTION

Environmental problems in the past were considered as a part of the economic system and the rapid utilization of natural resources [1]. It took many years to consider the established ways that materials were used (feedstocks), the initial design of chemical processes, the hazardous properties of products, the energy consumption and other parameters involved in the manufacture of products (life cycle, re- cycling, etc.).

The rapid development of new chemical technologies and huge number of innovative chemical products in the last decades forced the attention of environmentalists to remedial actions for the harm- ful impacts (monitoring environmental pollution, reduction of pol- lutants, recycling, etc). However, the most efficient way to lower the negative impacts is to design and innovation in the manufacturing processes, taking into account energy, materials, atom economy, use and generation of secondary materials which are hazardous and fi- nally the life cycle of the products and their practical recycling into new materials.

Green Chemistry involves another more environmental-friendly synthetic routes, and was another area for production of chemicals on industrial scale with the mantra —*'Think Green'*. Traditionally, chemical engineers have been more concerned about selectivity than conversion. Green technologies investigate alternate reaction conditions, alternate (solvent-free) media and even alternate energy sources [2].The design of chemical products and processes that re- duce or eliminate the use and generation of hazardous substances is the most fundamental approach for pollution prevention. Green chemistry addresses the need to produce the goods and services that society depends on in a more environmentally benign manner. Life-saving pharmaceuticals can be produced while minimizing the amount of waste generated, plastics that biodegrade can be synthe- sized from plants, and reactions can be run in water rather than in traditional organic solvents by applying green chemistry principlesto chemical products and processes.

Role of Green Chemical Technology

Green chemical technologies have eliminated waste, improved safety, enhanced security, and saved industry money. This paper describes the principles of green chemistry, provide industrial and academic examples of greener technologies, and highlight the eco- nomic benefits of adopting environmental friendly processes. The chemical process industry aims particularly at energy, capital expen- diture and variable feedstock cost savings due to fierce global com- petition and requirements for sustainable development. Increasingly novel processes are used in the industry to achieve these aims[3].
They are used in:
a) existing processes to renew parts;
b) process redesigns based on existing feedstock and catalysts;

c) innovative processes (new feedstocks, new catalysts, new pro- cess routes, new multifunctional equipment).

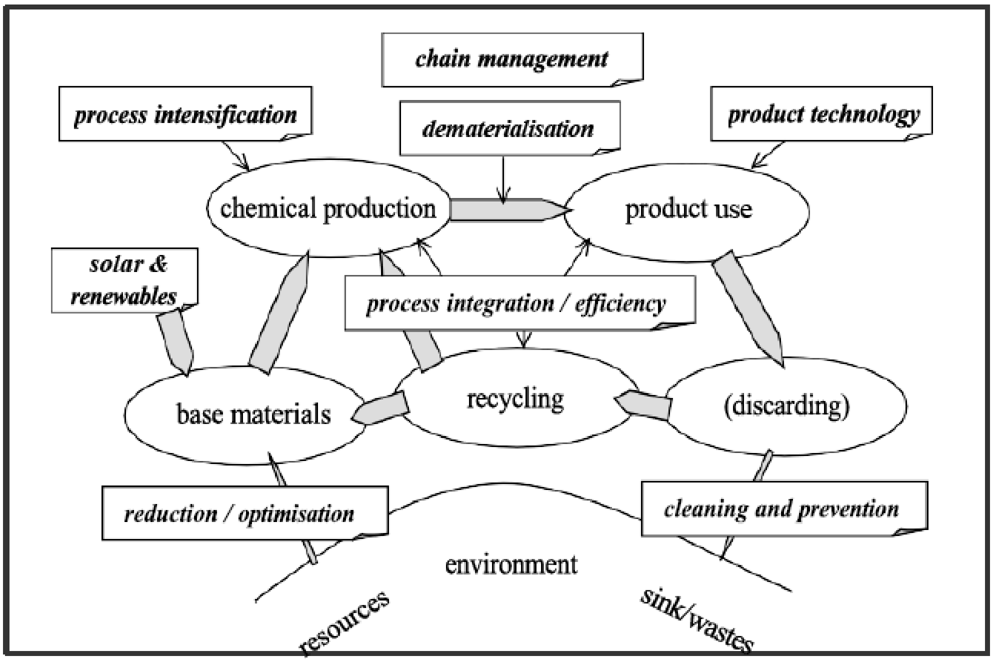

Fig. 1:*Focal Areas of Chemistry and Chemical Engineering for Sustain- able Development [3].*

The escalating globalization of the chemical process industries (CPI) is bringing an environmental awareness to various corners of the world at a pace never anticipated in the past. Green Chemical Engineering (GCE) is much more than a method for focusing en- vironmental problems[3].It recommends a framework for achiev- ing innovation. Time and again, companies looking to the future through the lens of GCE have enjoyed tremendous environmental and economic returns. Thus GCE has ways to enhance the envi- ronment also have encouraging impacton the client's bottom line. Avoiding the generation of waste (including energy) or pollutants can often be more cost-effective than controlling or disposing of pollutants once formed. Sustainable development is often used syn- onymously, but is more of an economical term describing how our economy shoulddevelop, and implying that rise in quantity is not necessarily the goal, but rather an increase in quality [4].

Sustainability Concepts

Sustainable development has become the accepted convention for global economic development and environmental protection since the end of the twentieth century.

The three major aspects of sustainable development are environ- ment, economy, and community [4]. In this context, it is necessary to consider the following steps [4,5].

i). The natural step
ii). Pollution prevention
iii). Design for environment
iv). Eco-efficiency
v). Eco-effectiveness
vi). Cradle-to-cradle design
vii). Industrial ecology
viii). Environmental management, Systems/sustainable management Systems

Pollution Prevention

Pollution prevention integrates the concepts of source reduction and recycling. Source reduction is nothing but those multimedia activi- ties that avoid waste generation and contaminant discharge. Recy- cling, for the purposes of pollution prevention, is a process in which a waste material is reused in the original manufacturing process or another process.

Design for Environment*(DfE)*:

Design for Environment (DfE) is the logical consideration during design of issues associated with environmental safety and health over the complete product life cycle.

Eco-Efficiency

Eco-efficiency has been portrayed as doing more with less. It in- cludes reducing waste, pollution and natural resource reduction (thus incorporating the concept of pollution prevention). Eco-effi- ciency is possibly the simplest way to go, and the logical follow- up to the progress that has been made in the area of environmental management[5]. After which comes a time of "beyond compliance", where businesses are finding that it can be to their benefit to not just adhere to the letter of the law, but to go beyond it.

Eco-Effectiveness

Proponents of eco-effectiveness point out those natural systems asinefficient, but they are certainly effective, and signifythe ideal systems, which our systems must imitate in order to achieve sustain- ability.

Environmental Management, Systems/Sustainable Management Systems

A typical environmental management system includes, establish- ment of an environmental policy that includes commitments to continual improvement, compliance, and pollution prevention, environmental planning to identify major environmental impacts, controlling these activities to minimize their impact on the environ- ment; and setting environmental performance objectives and targets and tracking progress toward meeting them [6].

Sustainability management systems are similar, but go one step fur- ther in that they provide a sustainability-based framework on which to base the targets developed by the EMS. One example is the com- bination of TNS with EMS.

Twelve Principles of Green Engineering

Green engineering principles are based on the green chemistry prin- ciples, given by Paul Anastas and Julie Zimmerman to help guide chemical engineers. [1,2] As for the Green Chemistry principles, the twelve Green Engineering principles recommend a basis for chemi- cal engineers to apply to design a new materials, products, processes and systems.

Making products, processes and systems more intrinsically benign can be done by either changing the inherent nature of the system, or changing the circumstances/conditions of the system to lower the issue of toxins and allied exposure to damaging effects, or both. The twelve principles are summarized as follows[1, 2].

1) Inherent rather than circumstantial

The inherent nature of the chosen material should be taken into ac- count toguarantee that it is as benign as possible (i.e. non-toxic, and/ or minimum energy and materials inputs necessary to finish the pro- cess).

2) Prevention instead of treatment

Materials and processes that produce minimum waste should be utilized. Thus we can prevent expenditure and hazard linked with substances that would otherwise have to be treated and disposed off.

3) Design for separation

Products should be intended with physical and chemical properties that allow self-separation processes, to decrease garbage and con- serve in separation operation time and costs.

4) Maximize mass, energy, space and time efficiency

Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency

5) Output-pulled versus input-pushed

Through the use of energy and material, one can design products, processes, and systems as "output-pulled" rather than "input- pushed"

6) Conserve complexity

Surrounded entropy and complexity must be observed as a savings when deciding design selection on recycle, reuse, or favorable dis- position.

7) Durability rather than immortality

Products should be designed to have a targeted lifetime, to prevent environmental issues such as waste to landfill, persistence and bio- accumulation.

8) Meet need, minimize excess

New tools should be discovered that focus on explicit requirements of the customer to reduce waste and cost. Design for excessive ca- pacity or capability result should be considered a design flaw.

9) Minimize material diversity

Products should be designed with less material variety to generate more alternatives for recyclability and reuse.

10) Integrate local material and energy flows
Design of products, processes, and systems must comprise integra- tion and interconnectivity with available energy and materials flows.
11) Design for commercial 'afterlife'
Products, processes and systems should be designed so their com- ponents can be reused or reconfigured to maintain their price and usability for new products.
12) Renewable rather than depleting
Renewable materials should be used so that the source can be re- loadedand affordpracticallyunlimited service with minimal, if any, waste.

Some Recent Developments and Examples of Green Technology
Scientists from all over the world are applying their creative and innovative skills to develop new processes, synthetic methods, ana- lytical tools, reaction conditions, catalysts, etc. under the new green technology envelope [7, 8]. Some of these are:
i). A continuous process and apparatus converts waste biomass into industrial chemicals, fuels, and animal feed. Another pro- cess convert's waste biomass, such as municipal solid waste, sewage sludge, plastic, tires, and agricultural residues, to useful products, including hydrogen, ethanol, and acetic acid.
ii). A method for mass producing taxol by semi-continuous culture of the Taxus genus plant.
iii). A fermentation method for the production of carboxylic acids.
iv). A method of partially oxidizing alcohol, such as methanol to ethers, aldehydes, esters or acids, by using a supercritical fluid mobile.
v). A process for manufacturing a fluoropolymer by using super- critical carbon dioxide.
vi). Aneconomical method of producing ethyl lactate– a non-toxic solvent derived from corn.
vii). A variety of 'organic solvents', for example, bioethanol, that are worker friendly and environmentally sound.
viii). A novel environmentalfriendly technology in mixed metals re- covery from spent acid wastes has been used to recover zinc and ferrous chloride from pickle liquor.
ix). The demand for nonionic surfactants is increasing. Aninnova- tive example of this is alkyl glycoside, which is made from sac- charide. This product can be used as a replacement for alkyl aryl sulphonate anionic surfactants in shampoos.

Use of Alternative Basic Chemicals as Feedstocks in Chemical Industry and Research
So far we know from experience of the last 50 years that the major- ity of raw chemicals and starting materials not only for the chemical industry but also for other industries were the products of the petro- chemical industry.

i). Renewable feedstocks and raw materials
Green chemical technology needs to change into renewable feed- stocks. The second most desired property of basic starting materials is their lower toxicity and their environmental impact[8]. Health and safety protection of workers andenvironment is thehighest priority. Green chemistry suggests change of direction into biological raw materials (plant and animal waste, products from fermentation of plant waste, biogas, etc).
ii). Oleochemistry-New biological starting materials
Fats and oils (from plants and animals) as oleochemical raw mate- rials can become a new source of chemical feedstocks. Already a series of raw materials exist in the market with many applications in cosmetics, polymers, lubricating oils and other products.
iii). Photochemistry.-New Chemical Processeswith the Aid of Light
Green technology puts a lot of prominence on photochemical reac- tions in chemical processes. Light (ultraviolet and visible) can be- come amajor catalyst for many reactions, replacing toxic metals in many reactions. Scientists believe that photochemistry has immense potential and many research innovations and applications were in- troduced in the past years.
iv). Photocatalytic synthetic routes with Titanium dioxide (TiO_2)
In the last decades various research studies have shown immense as- surance for using $TiO_2$for photocatalyitic industrial reactions under visible light. The energy use is minimized, waste products are very low and the yields are much higher than conventional reactions.
v). Photocatalytic oxidations. Waste and toxic chemicals decomposition
TiO_2 and other metallic oxides (Fe_2+) can be used in photocatalyt- ic oxidations for the decompositions of toxic and waste chemical materials. These decompositions, especially used for polychlori- nated compounds, phenols, etc, can produce neutral chemicals with minimum toxicity. A useful mixture is Fe_2+/H_2O_2 (Fenton reagent) whichcan decompose toxic industrial waste with the help of light.

vi). Waste Biomass as chemical feedstock, biomaterials and biofuels

The progress of the last decade into the use of biomass for the pro- duction of various materials was very remarkable. It was identified for decades that biomass from agricultural processes was wasted. [6,7] Scientists examined many aspect of biomass and it is found to be effective. Biomass is considered anextremely important problem of sustainability with increasing fossil fuel value.

vii). Biodegradation of biomass for biogas andbiodiesel

Biomass is well recognized for its use for biofuels, especially from organic waste in landfills. Biomass, through chemical and physical processes can be used for the production of biodiesel.

viii). Biocatalysis and biotransformations in the Chemical industry

Biocatalysis is considered particularly green technology with many applications which are considered benign for the environment and energy efficient. Enzymes have been used for many synthetic chem- ical routes with enormous rewards in the food and pharmaceutical industries.

ix). Capture or sequestration of carbon dioxide

Green chemistry is implicated in carbon dioxide reduction in chemi- cal industries[8, 9]. Climate change and the phenomenon of green- house effect due to CO_2 emissions are considered as anextremely important environmental problem by Green chemists.

Applications of New Methodologies in the Synthesis of Chemical Compounds

Some of the important changes in the synthesis of chemicals under GCE principles and alternative methods are discussed in this sec- tion.

i). Ionic liquids in organic synthetic routes

Ionic liquids are used significantly in recent years as alternative sol- vents in organic synthesis. These substances are called liquid elec- trolytes, ionic melts, ionic fluids, fused salts, liquid salts, or ionic glasses. Ionic liquids have many applications, as powerful solvents and electrically conducting fluids (electrolytes). They are believed as good candidates for future progress that can give “green” creden- tials to their use and applications [10, 11].

ii). Organic synthesis in water

Water was regarded as for many decades as a medium that was too avoided as solvent for synthetic organic chemistry. Water proved to be an excellent solvent for many synthetic methods. The most interesting example of water as a solvent is the Diels-Alder organic synthesis [2,12].

iii). Organic synthesis in polyfluorinated phases

In these techniques chemists are using polyfluorinated two-phase systems of solvents which dissolve catalysts with a long hyper- fluorinatedalcylo- or aliphatic chain. Reagents are dissolved in an organic solvent which is insoluble in the hyperfluorinated phase. Warming up the mixture speed up the reaction with excellent yield of products.

iv). Supercritical carbon dioxide and supercritical water

Supercritical fluid is called any liquid substance at a temperature and pressure above its critical point, where distinct liquid and gas phases do not exist.It can diffuse through solids like a gas, and dis- solve materials like a liquid. In addition, close to the critical point, small changes in pressure or temperature result in huge changes in density, allowing many properties of a supercritical fluid to be “fine- tuned”.

v). Use of microwave techniques for organic synthesis

Microwave furnaces are now common for food warming and cook- ing. Their use in organic synthesis implemented many years ago and their success in organic synthesis with “green’ criteria are very well recognized.Already, there are many research papers and appli- cations for microwave organic synthesis with high yields, without solvents, low waste and very low energy requirements[11].

vi).Sonochemistry-The use of ultrasound for synthesis

Chemical reactions can be enhanced by sonic waves and by ultra- sound. These are very advanced “green” techniques with outstand- ing high yields. There are three classes of sonochemical reactions: homogeneous sonochemistry of liquids, heterogeneous sonochem- istry of liquid–liquid or solid–liquid systems, and, extend beyond with the previous techniques, sonocatalysis. The chemical improve- ment of reactions by ultrasound has been explored and has valu- able applications in mixed phase synthesis, materials chemistry, and biomedical uses [3,10].

II. CONCLUSIONS

The environmental and climatic issues facing across the globe are widely recognized as daunting problems. Therefore, green technolo- gies and ecological sustainable development is vital as the quality of life is declining. We have had major progress in technology causing depletion of natural life sustaining resources, especially clean air and water. These problems are causing substantial environmental, economic and social impairment on a worldwide scale. Sustainable development implies that renewable resources should be used wher- ever possible and that nonrenewable resources should be husbanded (e.g., reduced and recycled) to extend their viability for generations to come.The paper reviews the trend towards sustainability and green technologies in the chemical process industry (CPI). A broad review of state-of-the-art green technologies in the understanding and application of sustainability with few case studies highlighting the economic benefits of adopting green processes from a chemical engineering viewpoint is addressed. Green technologies increasing- ly uses renewable resources; reduce wastes, pollutants, emissions; recover, reuse and recycle; reduce the pressure on natural resources and restore the balance of the ecosystem and biosphere and ulti- mately help in providing "ecologically sustainable development". These technologies are, therefore, feasible, cost-effective, environ- mentally advanced and most appropriate to the climatic, economi- cal, geographical, ecological and social conditions of the country.

This aim can only be achieved by developing new environmental friendly, safe and non-toxic materials and their based innovative technologies. Therefore CPI must encourage sustainable develop- ment by investing in green technologies and ensure increased adher- ence to safety, health and environmental standards.

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